Studies of Ionospheric Irregularities: Origins and Effects

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LONG-TERM GOALS

We have two long-term goals. The first goal is to understand the electrical properties of the upper atmosphere and space environment to better assist designers and users of space systems and technology. The second goal is to educate the next generation of leaders in space science and engineering.

OBJECTIVES

The scientific objectives of the project are:

(1) To investigate space weather and its effects on GPS, including the characterization of L-band scintillations and scintillation effects on GPS signals and receivers;

(2) To investigate the origin of ionospheric irregularities, which lead to ionospheric scintillation storms, through deployment of GPS scintillation receivers at equatorial latitudes, regionally in South America, at mid-latitudes (Hawaii, Ithaca, Puerto Rico, Utah), and at high latitudes (Norway);

(3) To develop GNSS receivers (WAAS, Galileo, and modernized GPS) that can assess the effect of scintillations and space weather on modernized GNSS signals;

(4) To develop space-based GPS receivers for sounding rocket and satellite applications that can remotely sense the ionosphere, thermosphere, and mesosphere.

Our research focuses on the study of space weather and the impact of space weather on GPS and GNSS receivers. Our approach is primarily experimental, and we have a reputation for producing cutting-edge instrumentation and developing successful experiments. The vast majority of the universe exists in a plasma state and we focus on our own upper atmosphere and ionosphere as natural laboratories for studying space weather and as an environment that affects satellites and their signals. This yields a mix of applied and curiosity-driven research. By primarily employing sounding rockets

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and ground-based instrumentation, graduate students are able to participate in the full range of research and develop into future leaders. For example Cornell University development of a GPS receiver for measuring fast amplitude scintillations has led to global program with receivers deployed at multiple sites across South America, Africa, and China. Several PhD students and postdocs from Cornell and Brazil have been trained using these receivers. This receiver not only monitors ionospheric scintillation but additionally measures ionospheric drifts. This effort also leverages our development of GPS software receivers and space-based GPS receivers.

APPROACH

Our scientific strategy emphasizes experimental development. We have chosen this route because the field of space science, especially that investigating the electrical properties of space, is still experimentally limited. Theories of space physics and space plasma physics are quite plentiful, but discriminating measurements are few and far between. Within this context one may well ask what areas need the most attention. The answer concerns nonlinear problems involving plasma waves and electric fields in collisionless environments and turbulent media. Incidentally, these areas are also examples that, at one extreme, can test theories of basic plasma physics and, at the other extreme, are important for the development and application of new communication and navigation technologies.

For this research our approach has been first to develop GPS receiver capable of measuring scintillations and other space weather effects. Our first receiver (SCINTMON) was also the first GPS receiver to measure fast L1 amplitude scintillations. Subsequently this design was copied by several other receiver manufacturers. The SCINTMON receiver has recently been upgraded to track WAAS signals. Our GPS receiver design continued with the development of digital storage receivers, which capture the entire GPS band width (L1 and L2), and software receivers that post process or analyze the GPS signals. Currently we are developing real-time GPS software receivers on DSP chips. These receivers have been demonstrated on PC platforms.

With the development of SCINTMON and digital storage receivers, the next step was to deploy them globally for measuring space weather effects including scintillations. Our approach is to give GPS receivers away "free" to collaborators, who then operate the receivers in regions of geophysical interest and share their data with us. This approach has been highly successful and we have established a regional chain of roughly 20 GPS scintillation receivers in South America (mostly Brazil) from the equatorial anomaly to the geomagnetic equator. Other receivers have been placed in Hawaii, Utah, Ithaca, Puerto Rico, Eritrea, Norway, and China. We are also extending our expertise in ground-based receivers to space flight. Three receivers were launched in a sounding rocket investigation of the northern lights and we are working with two colleagues (Dr. Mark Campbell and Dr. Mason Peck) at Cornell to create GPS receivers for a micro and pico-satellite projects. The CUBEsat instrument was designed to sense ionospheric scintillations of GPS signals in orbit for the first time. The CUSat uses our GPS receivers as part of the In-Orbit Inspection Nanosatellite Technology Flight Demonstration (INTech) project, which is funded by ONR. Both the CUBEsat and INTech projects use a GPS simulator acquired through DURIP funding.

WORK COMPLETED
   (1)   Made the first observations of solar radio bursts affecting GPS signal quality.
   (2)   Broke the PRN code of the first Galileo satellite.

(3)   Successfully demonstrated software receiver GPS signal acquisition and tracking using a DSP chip.

(4)   Distributed three scintillation receivers to Norway in collaboration with Dr. Cathryn Michell at the U. of Bath and one scintillation receiver to the Southwest Research Institute.

(5)   Completed the first rigorous study of inferring scattering height, zonal velocity, and vertical velocity from scintillation/fade drifts measured with spaced receivers on the ground.

(6)   Upgraded Cornell receivers at Ithaca, Puerto Rico, and Hawaii to measure WAAS scintillations.

(7)   Developed a scintillation receiver for measuring the WAAS signal on L1.

(8)   Demonstrated a real time dual-frequency civilian code (C/A L2CS) software receiver.

(9)   Developed an off-line dual-frequency civilian code (C/A and L2CS) software receiver.

(10) Developed an off-line dual-frequency P(Y) code software receiver.

RESULTS

With respect to items (10), (9), and (8) Cornell University has an international reputation for excellence in developing software receivers, having already developed the first single frequency C/A code 12 channel real-time software receiver. This effort has continued with the development of non-real time or off-line receivers that process received and stored signals as well as real time receivers. We now focus on dual-frequency receivers. There are several reasons for developing non-real time dual-frequency receivers. In the case of the P(Y) dual-frequency codes the bandwidth requirements are simply too large to be processed in real time. In the case of the dual-frequency civilian codes, this non-real time receiver is a first step to producing real time receivers. In addition, the non-real time receivers are excellent instructional tools for graduate students to understand how GPS receivers operate and to explore the operation with their own ideas. This includes examining frequency loops versus phase lock loops, acquisition strategies, and weak signal tracking.

Presentation of a graphic demonstrating the operation of a software receiver is somewhat contrived, so instead we illustrate one of the diagnostics used to evaluate receiver operation with real data. Figure 1 shows the broadband signal strength of a single satellite as function of code phase and Doppler shift. Toward the middle of the figure is a clear peak in power, which is the signal. Software receivers then track this peak by continuously adjusting the code phase, with a delay lock loop, and the Doppler shift, with a frequency lock loop. Once the signal is being tracked, the receiver then looks for jumps in signal phase by π that are produced by data bit transitions. The data bit transitions are then converted to bits (by resolving the -1 ambiguity) and the rest is straightforward. This effort in off-line receivers has led to demonstration of a real time L1/L2C software receiver running on a PC. We are now porting this code to a DSP chip to create a more robust system.
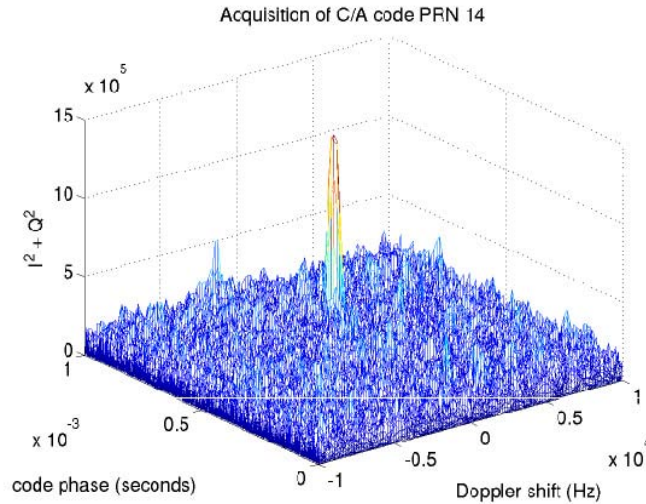
Acquisition of C/A code PRN 14

Figure 1. Example of a real GPS signal as a function of code phase and Doppler shift.

With respect to items (6), and (7), the wide area augmentation system (WAAS) was commissioned by the FAA on July 10, 2003 and is now an operational system. The WAAS signal is transmitted on the L1 frequency with a pseudorandom code not assigned to any of the 32 allowed GPS codes. Hence, a GPS receiver, which can reproduce the WAAS codes, can track the WAAS signal as if it were a GPS satellite. We have re-designed the Cornell scintillation receiver, called SCINTMON, to perform this function. The receiver has been deployed in Puerto Rico, Ithaca, and Hawaii, and was included in a recent campaign in Brazil.

Figure 2 shows what we believe to be the first observations of ionospheric scintillations on the WAAS signal. Two examples are displayed: one from Hawaii and one from Brazil. These are modest examples of scintillations with a maximum S4 index of about 0.6. The WAAS signal complements the GPS signals with some specific advantages. The WAAS signal comes from a geostationary satellite so that its elevation and azimuth do not change with time. As a result there are much fewer multipath fluctuations that mimic scintillations and the average signal strength is constant. The apparent lack of motion in the sky also implies that the signal path is not moving with respect to the ionosphere, as opposed to GPS signals whose ionospheric puncture points move at 10-100's of m/s. Hence, the inference of ionospheric drifts from the scintillation drifts is more straightforward. Since there is an implicit altitude assumed for correcting the GPS puncture point velocity, the simultaneous measurement of drift velocity with GPS and WAAS can yield altitude information about the scintillation scattering layer [*Cerruti et al.*, 2005].
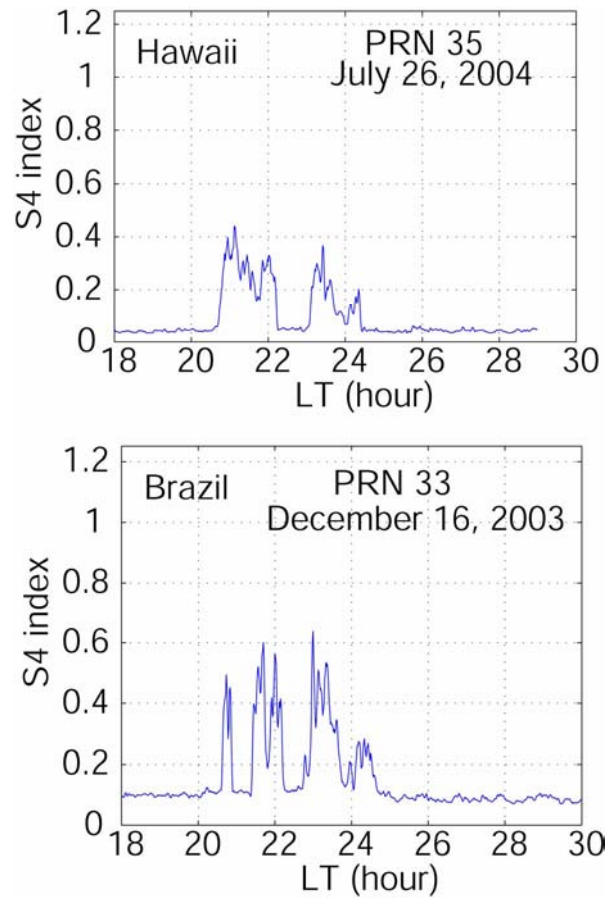
***Figure 2. Examples of WAAS scintillations
measured in Brazil and Hawaii.***

With respect to items (5) and (7), a rigorous study was performed to infer scattering height, zonal velocity, and vertical velocity from scintillation/fade drifts measured with spaced receivers on the ground. We believe that this is the first comprehensive analysis of GPS signals in this regard. Not only must the motion of the GPS ionospheric puncture point velocity be considered as mentioned above but a spherical earth with a realistic magnetic field was included.

With respect to (4) and (1) we have demonstrated two new space weather effects on GPS receivers: amplitude scintillations from auroral arcs and reduction of the signal-to-noise ratio or carrier-to-noise ratio from solar radio bursts. Figure 3 shows the first example of amplitude scintillations at high latitudes. The three receivers were located in Tromsø, Norway and the lower two plots show the fast amplitude samples from two Cornell SCINTMON receivers. For a period of 1-2 minutes, large amplitude fluctuations were present. This is the first example of GPS L1 amplitude fluctuations or scintillations at high latitudes of which we are aware. Further analysis demonstrated that the ionospheric puncture point of the satellite signal was over Svalbard and that at the time of the amplitude scintillations an intense auroral arc (substorm) was present.
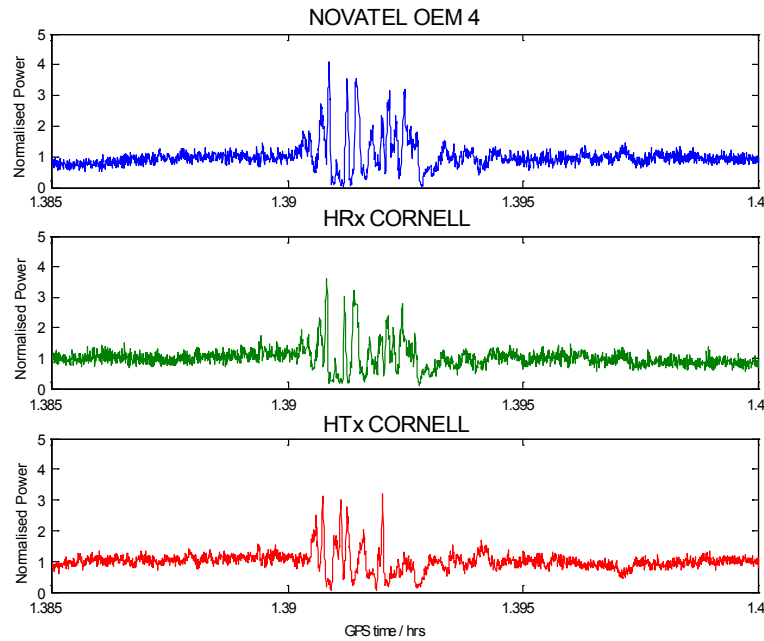
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Figure 3. Example of GPS amplitude scintillations at high latitudes.

Another new space weather effect on GPS signals was discovered by a Cornell SCINTMON receiver located at Arecibo in Puerto Rico. Because scintillations from irregularities in the ionosphere have only been previously observed at night, most SCINTMON receivers were only operated at night. However, the SCINTMON receiver located at Arecibo was operated continuously, including during the day. On September 7, 2005 a large solar flare occurred with a significant solar radio burst. Solar radio bursts are typically broadband over frequencies below 1 GHz to above 10 GHz, including the GPS L1 frequency at 1.6 GHz. The solar radio burst power is shown as a black line in Figure 4 with two events near 1735 UT and 1840 UT. The GPS carrier-to-noise ratio (C/No) is shown inverted (less C/No appears positive) as the gray data for three receivers. The Arecibo receiver is a Cornell SCINTMON receiver observing the GPS WAAS signal. The other two receivers were operated by the FAA and were also observing the WAAS signal. Clearly, all three receivers responded in unison to the solar radio bursts. Also, all three receivers were spatially separated in some cases by 1000's of km, although all of them were in sunlight. This result demonstrates the vulnerability of GPS and GNSS signals to solar radio bursts.
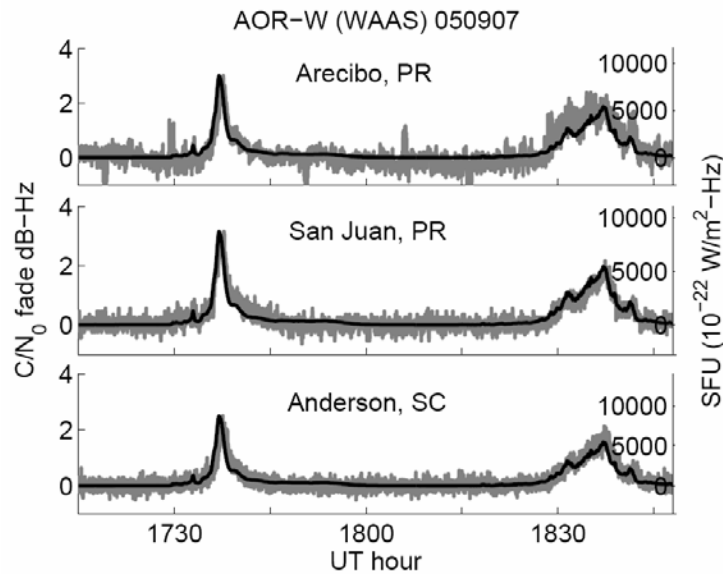
Figure 4. The effect of solar radio bursts on GPS carrier-to-noise ratio shown as gray data and inverted. Solar radio burst power is shown as black line.

IMPACT/APPLICATIONS

Our work with GPS receivers and measurement of scintillations continues to be important in understanding and predicting the behavior of GPS receivers in the presence of scintillations. In the future our receivers will be critical to evaluating the impact of space weather, including scintillations on GNSS signals. Our past work in determining the shape of fade patterns is important to understanding how velocity resonance will occur and potentially produce loss of lock or even loss of navigation in GPS receivers. Our recent work with the WAAS signals will lead to understanding the significance of scintillations on this system. Our continued development of software receivers looks to the future when modernized GPS signals will be available and dual-frequency measurements of TEC should be inexpensive.

The expansion of our GPS scintillation program to mid-latitudes has been very fruitful. Not only have we been able to show that field lines mapping to well above the equatorial ionosphere produce spread-F disturbances in Hawaii and Puerto Rico but we have also demonstrated that substantial (S4=1) scintillations can occur in the northern United States. Our continued deployment of receivers in the northern hemisphere will further characterize this environment.

Finally, the demonstration of solar radio bursts affecting GPS signals has significant consequences for GPS receivers during the next solar maximum. The solar radio burst on September 7, 2005 was modest and power levels 10-20 times larger than that shown in Figure 4 can be expected during the next solar maximum. This higher power level will cause all civilian dual-frequency GPS receivers to fail and will endanger single frequency GPS receiver operation.

TRANSITIONS

The first of the block II RM satellites, which transmit a civilian code on L2, was launched on September 25, 2005 and the second one should be launched in Fall 2006. We have developed a non-real time L1/L2C receiver and demonstrated operation of a prototype real time L1/L2C receiver to receive the signals on the new signals from these satellites. Our objective in the next year is to develop a robust, real time L1/L2C receiver based on a signal processing chip set that has a low production cost. This new receiver will become the next generation SCINTMON receiver and we plan to distribute it using the same "business plan" to obtain global coverage.

RELATED PROJECTS

Our NASA projects depend heavily on the funding of GPS receiver development. For example, the results from the ground-based GPS scintillation receivers were critical in determining goals for the LWS/Geospace Mission Definition Team report. The sounding rocket program at Cornell uses GPS receivers originally based on the scintillation receiver design.
http://lws.gsfc.nasa.gov/docs/Geospace/GMDTReportforWeb.pdf

The CUBEsat and CUSat programs, with which we are collaborating, use a receiver based on the Cornell sounding rocket design and the GPS signal simulator, purchased with DURIP funding, is being used to develop and test the CUBEsat and CUSat GPS receivers. Additional information can be found at http://www.mae.cornell.edu/cubesat/ and http://cusat.cornell.edu/.

We collaborate closely with Prof. Michael Kelley (Cornell) and Dr. Jonathan Makela (NRL), who make all-sky ionospheric images. Several joint papers have been published using imaging and GPS data at Hawaii. See http://www.cosis.net/abstracts/EAE03/05826/EAE03-J-05826.pdf.

REFERENCES

Cerruti, A. P., B. M. Ledvina, and P. M. Kintner, Measurements of equatorial scintillations on the WAAS satellite signal, *Radio Sci.*, in press, 2006.

Ledvina, B. M., P. M. Kintner, and J. J. Makela, Temporal properties of intense GPS L1 amplitude scintillations at midlatitudes, *Radio Sci., 39*, RS1S18, doi:10.1029/2002RS002832, 2004.

PUBLICATIONS

Aarons, J., M. Mendillo, B. Lin, M. Colerico, T. Beach, P. Kintner, J. Scali, B. Reinisch, G. Sales, and E. Kudeki, Equatorial F region irregularity morphology during an equinoctial month at solar minimum, *Space Sci. Rev., 87*, 357-386, 1999. [published, refereed]

Beach, T.L., and P.M. Kintner, Simultaneous Global Positioning System observations of equatorial scintillations and total electron content fluctuations, *J. Geophys. Res., 104*(A10), 22,553-22,565, 1999. [published, refereed]

Beach, T.L., and P.M. Kintner, Development and use of a GPS ionospheric scintillation monitor, *IEEE Trans. Geosci. Remote Sensing, 39*(5), 918-928, 2001. [published, refereed]

Beach, T.L., M.C. Kelley, P.M. Kintner, and C.A. Miller, Total electron content variations due to nonclassical traveling ionospheric disturbances: Theory and Global Positioning System observations, *J. Geophys. Res., 102*(A4), 7279-7292, 1997. [published, refereed]

Bhattacharyya, A., T.L. Beach, S. Basu, and P.M. Kintner, GPS studies of TEC variations and equatorial scintillations, *Proceedings of IES99*, JMG Associates LTD, 5A6-1 to 5A6-8, 1999. [published, refereed]

Bhattacharyya, A., T.L. Beach, S. Basu, and P.M. Kintner, Nighttime equatorial ionosphere: GPS scintillations and differential carrier phase fluctuations, *Radio Sci., 35*(1), 209-224, 2000. [published, refereed]

Cerruti, A.P., B.M. Ledvina, and P.M. Kintner, Measurements of equatorial scintillations on the WAAS satellite signal, *Radio Sci*., in press, 2005. [in press, refereed]

Ezquer, R.G., P.M. Kintner, M.A. Cabrera, S.M. Radicella, and B. Forte, Scintillations observed at Tucuman as observed from GPS signals: First Results, *Adv. Space Res., 31*(3), 741-747, 2003. [published, refereed]

Humphreys, T.E., B.M. Ledvina, M.L. Psiaki, A.P. Cerruti, and P.M. Kintner, Analysis of ionospheric scintillations using wideband GPS L1 C/A signal data, *Proceedings of the Institute of Navigation GNSS*, September 24-26, 2004. [published, refereed]

Humphreys, T.E., M.C. Kelley, and P.M. Kintner, GPS-based measurement of solar atmospheric tides, *Geophys. Res. Lett*., in press, 2005. [in press, refereed]

Humphreys, T.E., M.C. Kelley, N. Huber, and P.M. Kintner, Jr., The semidiurnal variation in GPS-derived zenith neutral delay, *Geophys. Res. Lett., 32*, L24801, doi:10.1029/2005GL024207, 2005. [published, refereed]

Hyosub, K., P.M. Kintner, E.R. de Paula, and I.J. Kantor, Latitudinal variations of scintillation activity and zonal plasma drifts in South America, *Radio Sci., 37*(1), 6-1 to 6-7, 10.1029/2001RS002468, 2002. [published, refereed]

Kelley, M.C., J.J. Makela, B.M. Ledvina, and P.M. Kintner, Observations of equatorial spread-F from Haleakala, Hawaii, *Geophys. Res. Lett*., *29*(20), 2003, doi:10.1029/2002GL015509, 2002. [published, refereed]

Kil, H., P.M. Kintner, E.R. de Paula and I.J. Kantor, GPS measurements of the ionospheric zonal apparent velocity at Cachoeira Paulista in Brazil, *J. Geophys. Res., 105*(A3), 5317-5238, 2000. [published, refereed]

Kintner, P.M., and B. Ledvina, A scintillation test pattern for evaluating GPS receivers, *Space Weather*, submitted, 2003. [published, refereed]

Kintner, P.M., H. Kil, and E. de Paula, Fading time scales associated with GPS signals, *Proceedings of IES99*, JMG Associates LTD, 1999. [published, refereed]

Kintner, P.M., P.W. Schuck, and J.R. Franz, Spaced measurements and progress in understanding space plasma waves, *Phys. Plasmas, 7*(5), 2135-2141, 2000. [published, refereed]

Kintner, P.M., J. Franz, P. Schuck, and E. Klatt, Interferometric coherency determination of wavelength or What are BB-ELF waves?, *J. Geophys. Res., 105*(A9), 21,237-21,250, 2000. [published, refereed]

Kintner, P.M., H. Kil, and E. De Paula, Fading time scales associated with GPS signals and potential consequences, *Radio Sci., 36*(4), 731, 2001. [published, refereed]

Kintner, P.M., H. Kil, C. Deehr, and P. Schuck, Simultaneous total electron content and all-sky camera measurements of an auroral arc, *J. Geophys. Res., 107*(A7), 1127, doi:10.1029/2001JA000110, 2002. [published, refereed]

Kintner, P.M., B.M. Ledvina, E.R. de Paula, and I.J. Kantor, Size, shape, orientation, speed, and duration of GPS equatorial anomaly scintillations, *Radio Sci., 39*, RS2012, doi:10.1029/2003RS002878, 2004. [published, refereed]

Kintner, P.M., B.M. Ledvina, and E.R. de Paula, An amplitude scintillation test pattern for evaluating GPS receiver performance, *Space Weather*, *3*, S03002, doi:10.1029/2003SW000025, 2005. [published, refereed]

Kintner, P.M., and B.M. Ledvina, The ionosphere, radio navigation, and global navigation satellite systems, *Adv. Space Res.*, *35*(5), 788-811, 2005. [published, refereed]

Kintner, P.M., B.M. Ledvina, and E.R. de Paula, GPS and ionospheric scintillations, *Space Weather*, submitted, 2006. [submitted, refereed]

Ledvina, B.M., J.J. Makela, and P.M. Kintner, First observations of GPS L1 amplitude scintillations at midlatitude, *Geophys. Res. Lett., 29*(14), 4-1 to 4-4, 10.1029/2002GL014770, 2002. [published, refereed]

Ledvina, B.M., M.L. Psiaki, S.P. Powell, and P.M. Kintner, A 12-channel real-time GPS L1 software receiver, *IEEE Transactions on Wireless Communications*, submitted, 2003. [submitted, refereed]

Ledvina, B.M., P. M. Kintner, and J. J. Makela, Temporal properties of intense GPS L1 amplitude scintillations at midlatitudes, *Radio Sci., 39*, RS1S18, doi:10.1029/2002RS002832, 2004. [published, refereed]

Ledvina, B.M., M.L. Psiaki, D.J. Sheinfeld, A.P. Cerruti, S.P. Powell, and P.M. Kintner, A real-time GPS civilian L1/L2 software receiver, *Proceedings of the Institute of Navigation GNSS*, September 24-26, 2004. [published, refereed]

Ledvina, B.M., M.L. Psiaki, S.P. Powell and P.M. Kintner, Bit-wise parallel algorithms for efficient software correlation applied to a GPS software receiver, *IEEE Transactions on Wireless Communications, 3*(5), 2004. [published, refereed]

Ledvina, B.M., and J.J. Makela, First observations of SBAS/WAAS scintillations: Using collocated scintillation measurements and all-sky images to study equatorial plasma bubbles, *Geophys. Res. Lett., 32*, L14101, doi:10.1029/2004GL021954, 2005. [published, refereed]

Ledvina, B.M., M.L. Psiaki, P.M. Kintner, and E.R. de Paula, Ionospheric scattering altitude estimation using closely-spaced GPS receivers, *Radio Sci.*, in review, 2005. [in press, refereed]

Ledvina, B.M., J.C. Little, S.M. Furgason, R.B. Harris, R.G. Mach, C. Brock, T.L. Gaussiran, E.G. Lightsey, M.L. Psiaki, S.P. Powell, and P.M. Kintner, Signal characteristics of the first broadcast L2C signal, Institute of Navigation Global Navigation Satellite Systems 2006 Annual Meeting, September 26-29, 2006, Fort Worth, TX. [in press, refereed]

Ledvina, B.M., M.L. Psiaki, T.E. Humphreys, S.P. Powell, P.M. Kintner, and T.L. Gaussiran, A real-time software receiver for the GPS and Galileo L1 signals, Institute of Navigation Global Navigation Satellite Systems 2006 Annual Meeting, September 26-29, 2006, Fort Worth, TX. [in press, refereed]

Makela, J.J., B.M. Ledvina, M.C. Kelley, and P.M. Kintner, Analysis of the seasonal variations of equatorial plasma bubble occurrence observed from Haleakala, Hawaii, *Ann. Geophys., 22*(9), 3109-3121, 2004. (special issue, 8/04) [published, refereed]

Psiaki, M.L., P.M. Kintner, Jr., and S.P. Powell, Rapid energy dissipation in a yo-yo-type wire boom deployment system, *Journal of Guidance, Control, and Dynamics, 23*(3), 483-490, 2000. (Also in *Proceedings of the 1999 AIAA Guidance, Navigation, and Control Conf.*, Aug. 1999, Portland, OR, pp. 1424-1436.) [published, refereed]

Psiaki, M.L., S.P. Powell, and P.M. Kintner, Jr., Accuracy of the Global Positioning System-derived acceleration vector, *Journal of Guidance, Control, and Dynamics, 23*(3), 532-538, 2000. (Also in *Proceedings of the 1999 AIAA Guidance, Navigation, and Control Conf.*, Aug. 1999, Portland, OR, pp. 751-760.) [published, refereed]

Psiaki, M.L., L.B. Winternitz, and M.C. Moreau, FFT-Based Acquisition of GPS L2 Civilian CM and CL Signals, *Proceedings of the Institute of Navigation GNSS*, September 24-26, 2004. [published, refereed]

Psiaki, M.L., T.E. Humphreys, S. Mohiuddin, S.P. Powell, A.P. Cerruti, and P.M. Kintner, Jr., Searching for Galileo: Reception and analysis of signals from GIOVE-A, *GPS World*, June 1, 2006. [published, refereed]

Psiaki, M.L., T.E. Humphreys, S. Mohiuddin, S.P. Powell, and P.M. Kintner, Searching for Galileo, Institute of Navigation Global Navigation Satellite Systems 2006 Annual Meeting, September 26-29, 2006, Fort Worth, TX. [in press, refereed]

de Rezende, L.F.C., E.R. de Paula, I.J. Kantor, and P.M. Kintner, Mapping and survey of plasma bubbles over Brazilian territory, *Inst. Navigation, 60*(1), in press, 2006. [in press, refereed]

Wiens, R.H., B.M. Ledvina, and P.M. Kintner, Climatologies of GPS scintillations, equatorial plasma bubbles, and ion drift speeds over Asmara, *Radio Sci.*, in press, 2005. [in press, refereed]

Wiens, R.H., B.M. Ledvina, P.M. Kintner, M. Afewerki, and Z. Mulugheta, Equatorial plasma bubbles in the ionosphere over Eritrea: Occurrence and drift speed, *Ann. Geophys. 24*(5), 1443-1453, 2006. (ISEA-11 special issue) [published, refereed]

PATENTS

Real-Time Software Receiver, January 10, 2003. [granted]

HONORS/AWARDS/PRIZES

The following paper received the "Best Student Paper Award" at the ION GNSS Conference in Fort Worth, Texas, September 26-29, 2006:

Cerruti, A., Observed GPS and WAAS signal-to-noise degradation due to solar radio bursts.